Towards More Frequent Terrestrial Reference Frame Updates

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Introduction

Outline

- **Notion** of Terrestrial Reference Frame (TRF) Updates.
- **Why** would TRF Updates be Useful?
- A Simple **Proof of concept**
  - The **How-To** of TRF Updates
  - Quality Assessment of TRF Updates
- Were TRF Updates feasible, **What would We Need** from the community in order for them to be distributed?

Why Would TRF Updates Be Useful? [1]

- **Frame Obsolescence**, i.e. frame degradation with time [see e.g. Blewitt, 2015]
- ITRF official products are **released at intervals of 3-to-5 years** (see *http://itrf.ensg.ign.fr/*)
- TRFs do not age well:
  - Quakes, equipment changes at ITRF sites introduce station position discontinuities and degrade the frame quality
  - 3-to-5 years in between ITRF releases acceptable tradeoff (new releases are **burdensome** for the analyses centers, IGS/GNSS in particular, because of the entire reprocessing of an ever-increasing dataset)
- **More frequent Frame Updates** might be used to alleviate obsolescence.

Why Would TRF Updates Be Useful? [2]

- To maintain the accuracy of TRFs over time by updating them as new data become available.
- To ensure the consistency over time of the Earth Orientation Parameters (EOPs) with the TRF *(EOPs get assimilated as well when updating the TRF).*
- To provide updates to the time series of geocentre motion (CM-CN) based on the assimilation of new data.

Methodology and Data Sets

TRF(2014) Products

	JTRF	ITRF	DTRF
IERS Comb Center	JPL-Caltech	LAREG-IGN	DGFI-TUM
Computational Code Name	KALREF	CATREF	DOGS
Frame Type	Time Series	Parametric	Parametric
Estimator	**Kalman Filter**	Least-square	Least-square [a]
Process Noise	Random Walk	None	None
Origin	Instantaneous SLR CM	Long-term SLR CM	Long-term SLR CM
Scale	Instantaneous VLBI/SLR	VLBI/SLR [b]	VLBI/SLR [c]
Orientation	NNR to ITRF2008	NNR to ITRF2008	NNR to ITRF2008

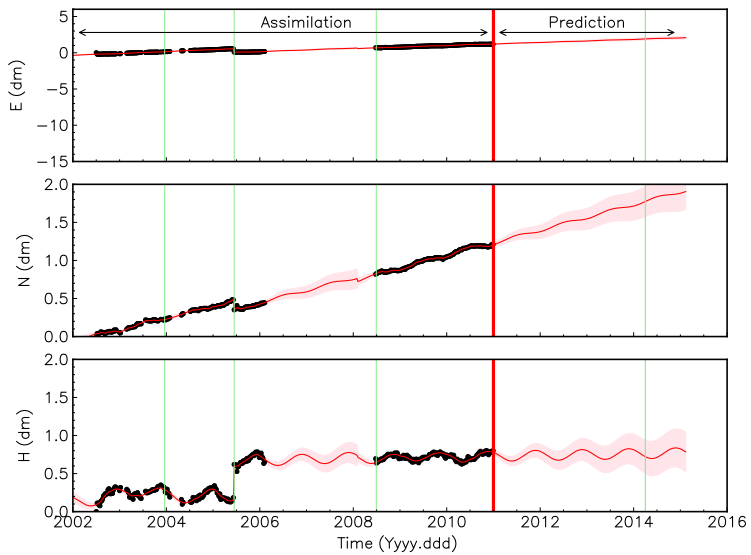
[a] Based on the inversion of accumulated Normal Equations
[b] Simple Average of VLBI and SLR Scales
[c] Weighted Average of VLBI and SLR Scales

KALREF. Frame Update & Prediction

- **Predictive Mode**

$$\underbrace{\begin{cases} X_k^- = \Phi_{k-1}\, X_{k-1}^+ + \mathcal{W}_{k-1} \\ \mathbf{P}_k^- = \Phi_{k-1}\, X_{k-1}^+\, \Phi_{k-1}^t + \mathbf{Q}_{k-1} \end{cases}}_{\text{Time Update}}$$

- **GNSS Station at Iquique (Chile)**



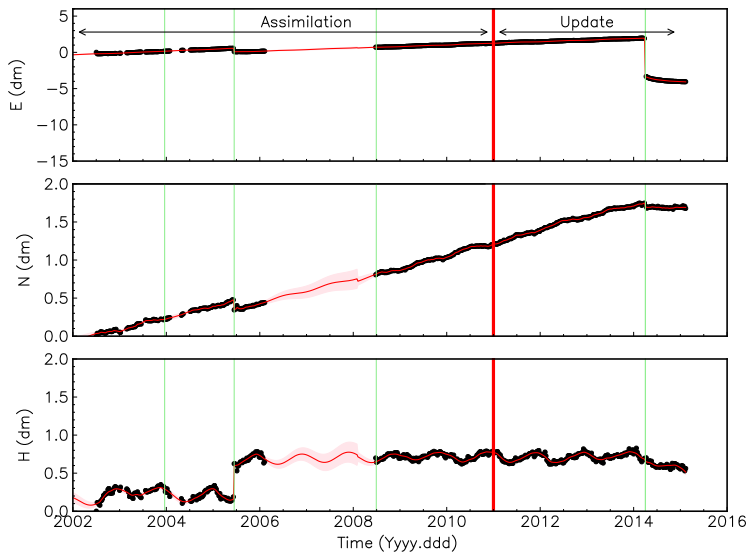
Black dots are position observations, whereas red solid lines are KALREF-derived. Solid green vertical lines mark position offsets. Light red-shaded envelopes represent $1-\sigma$ error bars.

KALREF. Frame Update & Prediction

- **Assimilative Mode**

$$\underbrace{\begin{cases} X_k^+ = X_k^- + \mathbf{K}_k \left(y_k - \mathbf{H}_k X_k^- \right) \\ \mathbf{P}_k^+ = \left(\mathbf{I} - \mathbf{K}_k \mathbf{H}_k \right) \mathbf{P}_k^- \end{cases}}_{\text{Measurement Update}}$$

- **GNSS Station at Iquique (Chile)**



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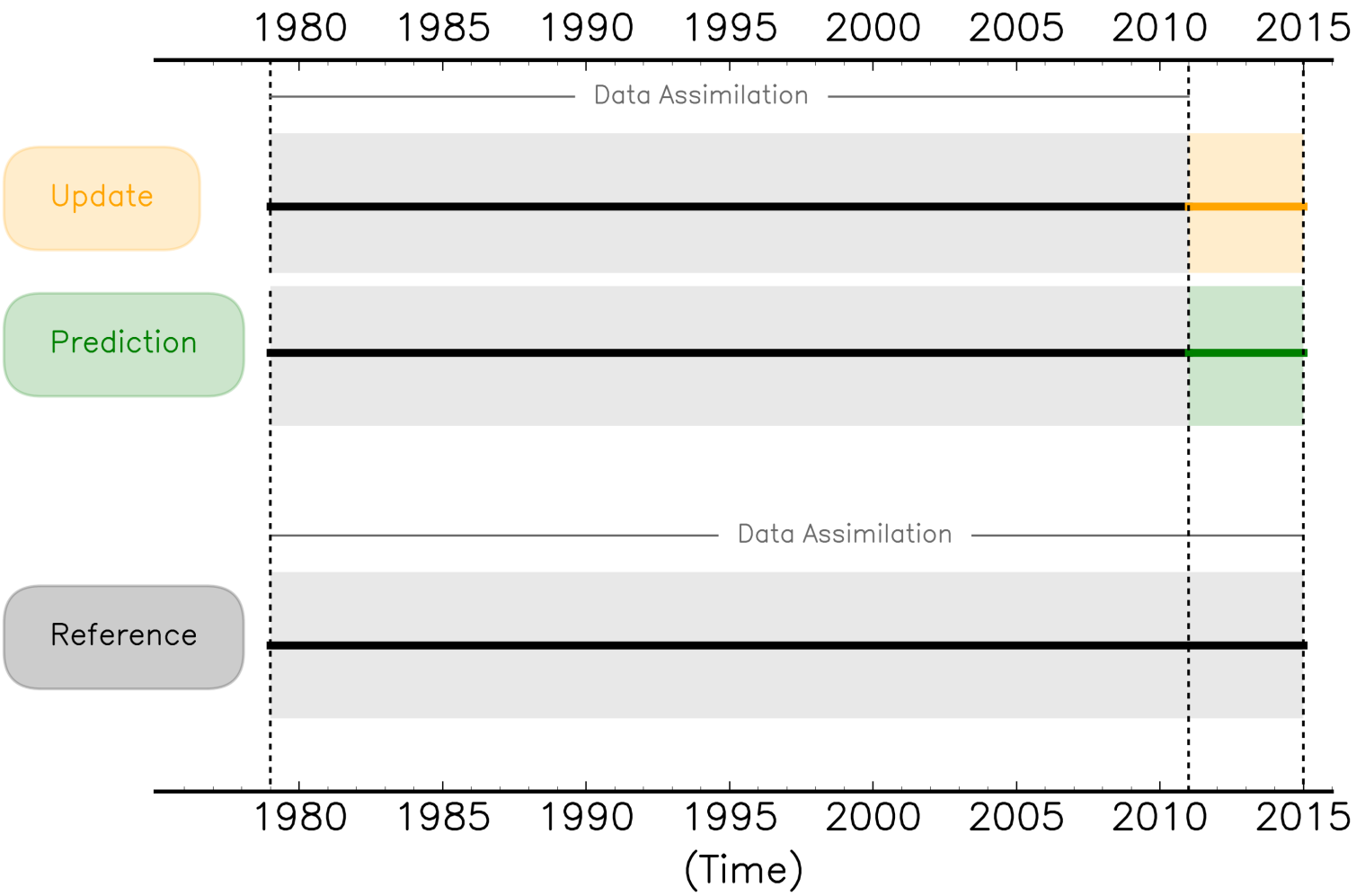
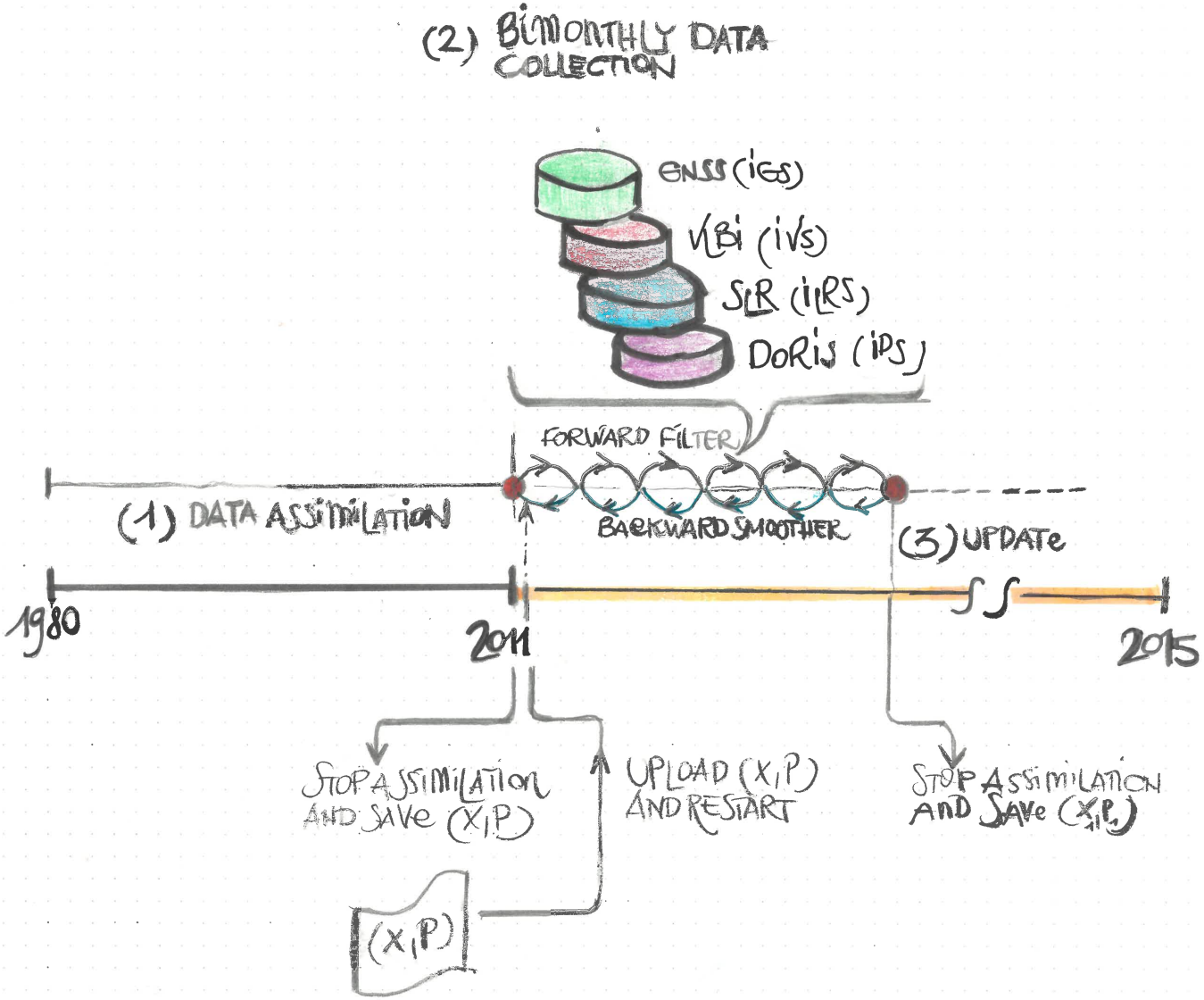
Combination Tests For our Proof of Concept

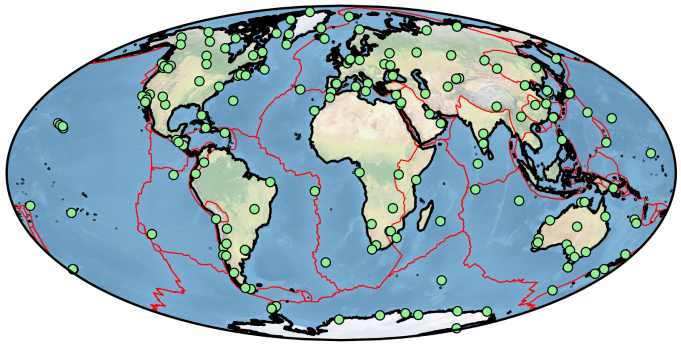


Updating the TRF – Sketch

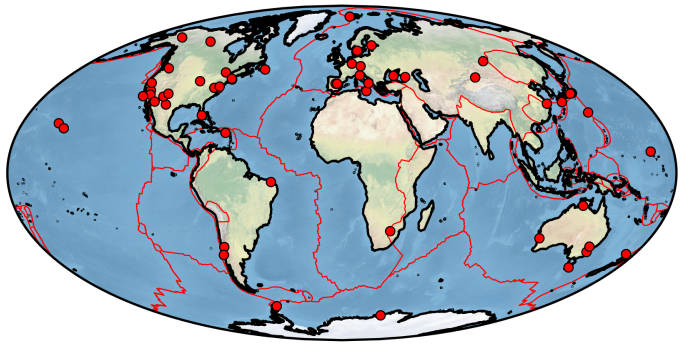


Global Space-Geodetic Network Adopted in Our Tests

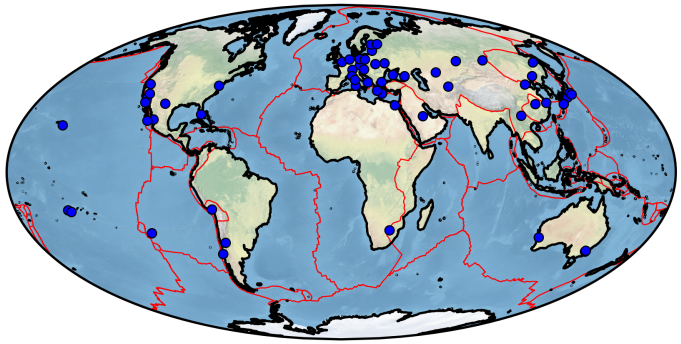
GNSS (195 Stations)



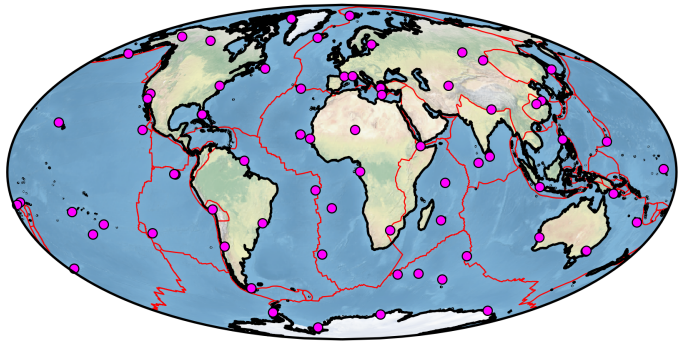
VLBI (71 Stations)



SLR (70 Stations)



DORIS (159 Stations)

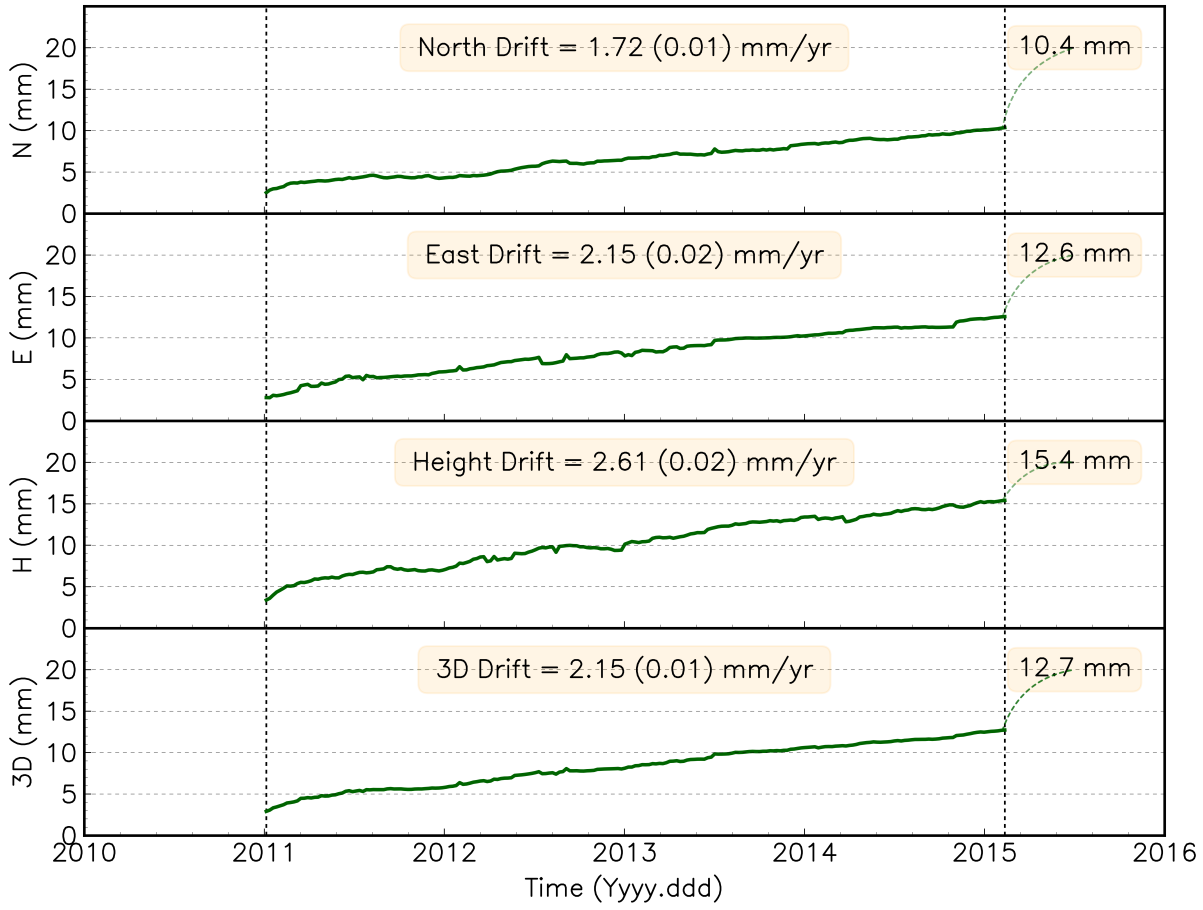


495 Stations with Observing History $>$ **2.5** years from input SINEX files to ITRF2014

Results

TRF Updates versus Predictions (WRMS)

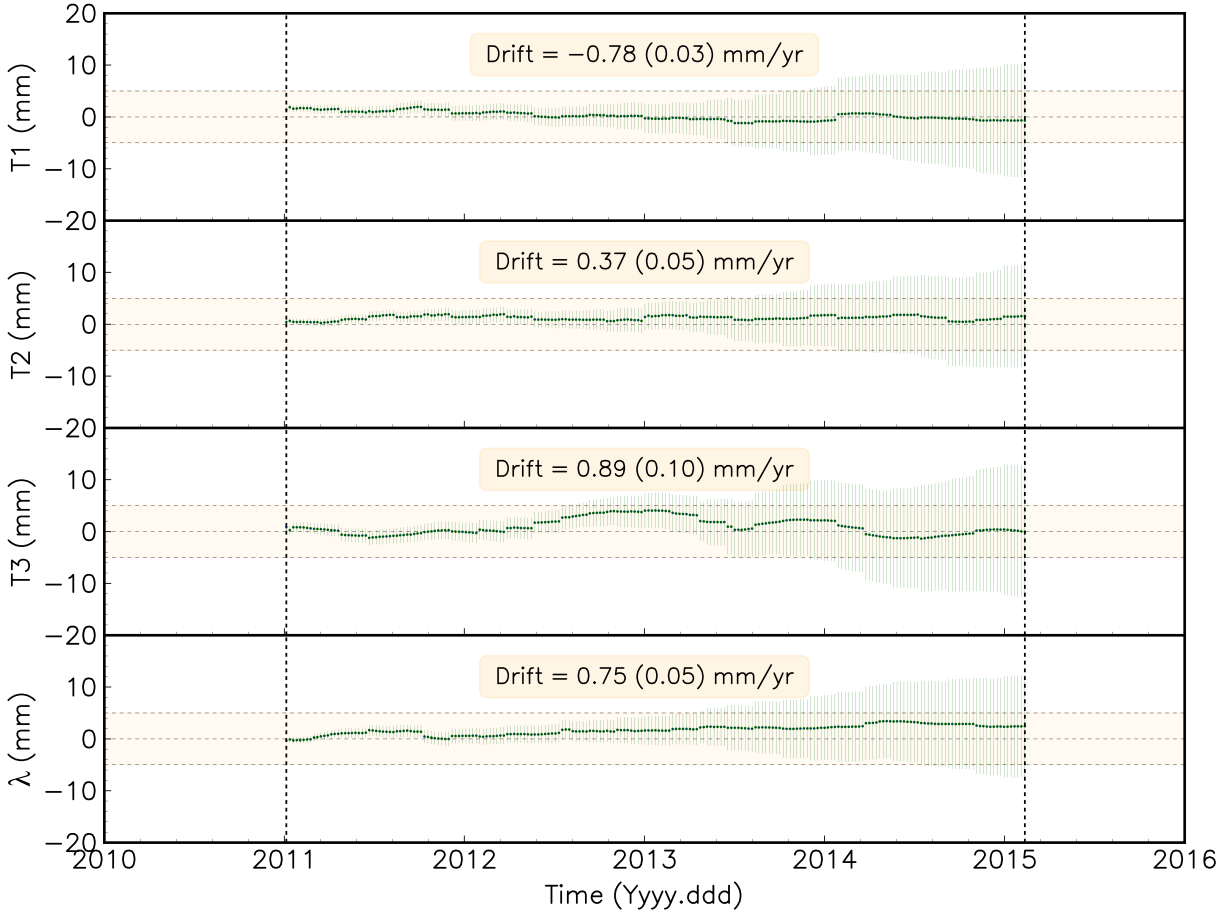
$$X_P = X_U + \overbrace{T}^{\text{Translations}} + \overbrace{\lambda \mathbf{I} \cdot X_U}^{\text{Scale}} + \overbrace{\mathbf{R} \cdot X_U}^{\text{Rotations}} \quad (1)$$



- WRMS are computed after the removal of the Helmerts from Equation (2)
- Sites characterised by large co-seismic, post-seismic displacements and position offsets have been **removed**

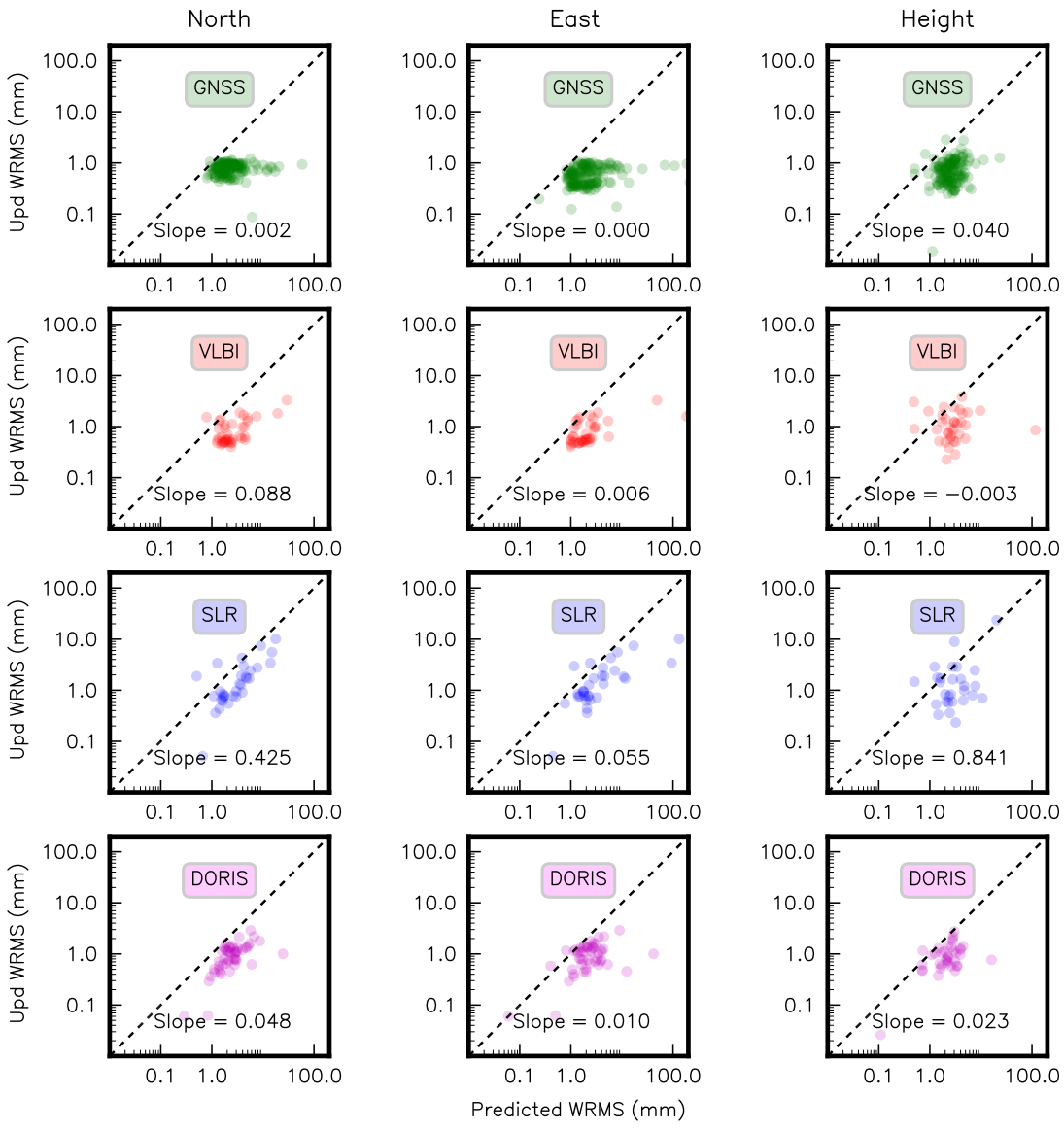
TRF Updates versus Predictions (Helmerts: T,λ)

$$X_P = X_U + \overbrace{T}^{\text{Translations}} + \overbrace{\lambda \mathbf{I} \cdot X_U}^{\text{Scale}} + \overbrace{\mathbf{R} \cdot X_U}^{\text{Rotations}}$$



- Seismic Sites have been removed when computing the Helmerts.
- Green-shaded envelopes represent $1-\sigma$ error bars.
- Orange-shaded rectangles represent the bounded region $[-5, +5]$ mm.

Scatterplots of the WRMS Differences (Pred/Upd - Truth)



Conclusions and Perspectives

Conclusions and Perspectives

- Frame Updates are doable and relatively easy to implement in a Kalman Filter framework.
- Frame Updates are beneficial in terms of reductions of the station position WRMS (our tests suggest the WRMS errors increase linearly with time and the WRMS drifts are in the order of $2-3$ mm/yr)
- Adoption of TRF products in predictive mode produces degradation in the frame defininig parameters (while smaller than the position WRMS, such degradation is particularly evident in T_z)
- For TRF updates to be released, we would need support from the Technique Centers. IGS and ILRS already provide operational products consistent with the IERS Conventions [Petit and Luzum, 2010] adopted for the ITRF2014 project.
- The low computational time would allow TRF Updates to be delivered with low latency.

References

G. Blewitt. Terrestrial Reference Frame Requirements for Studies of Geodynamics and Climate Change. In Springer International Publishing Switzerland, editor, *Reference Frames For Applications in Geosciences and Technology*, International Association of Geodesy Symposia, 2015. doi: 10.1007/1345_2015_142.

G. Petit and B. Luzum. IERS Conventions (2010). pages 1–179. International Earth Rotation and Reference Systems Service Central Bureau Bundesamt für Kartographie und Geodäsie Richard-Strauss-Allee 11 60598 Frankfurt am Main Germany, 2010. URL `https://www.iers.org/SharedDocs/Publikationen/EN/`

References II

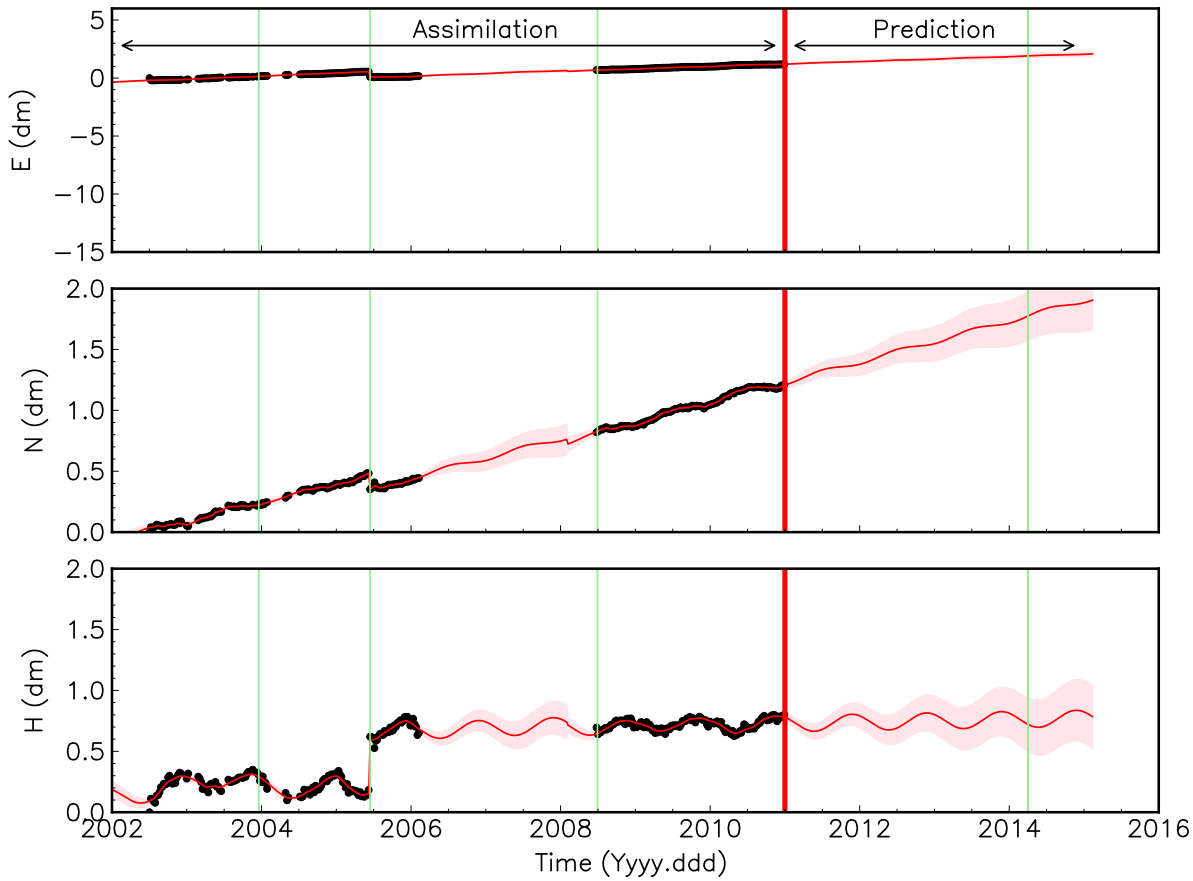
IERS/Publications/tn/TechnNote36/tn36.pdf?__blob=publicationFile&v=1. IERS Technical Note, No. 36.

Backup Slides

Dataset and Combination Setup

Dataset	SNX Files from IGS,IVS,ILRS,IDS for ITRF2014
Network	495 Stations
Frame Type	Time Series
Model	Trend, Annual
Process Noise	Station-Dependent Random Walk
Origin	Quasi-Instantaneous CM (SLR)
Scale	Quasi-Instantaneous SLR/VLBI
Orientation	No-Net-Rotation to ITRF2008

GNSS Station at Iquique (Chile) – Predictions



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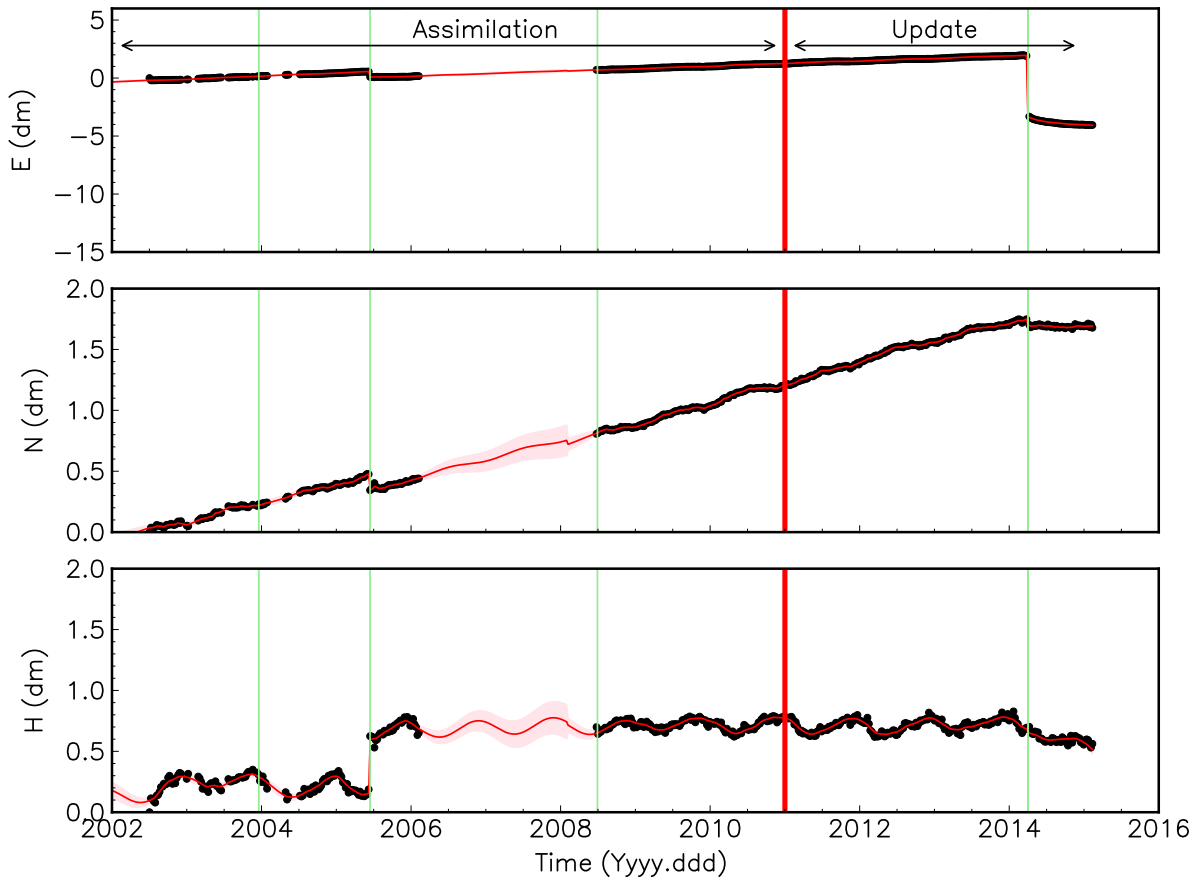
GNSS Station at Iquique (Chile) – Updates



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Updates versus Predictions (Helmerts: R)

$$X_P = X_U + \overbrace{T}^{\text{Translations}} + \overbrace{\lambda \mathbf{I} \cdot X_U}^{\text{Scale}} + \overbrace{\mathbf{R} \cdot X_U}^{\text{Rotations}}$$

Green-shaded envelopes represent $1 - \sigma$ error bars.

Orange-shaded rectangles represent the bounded region $[-5, +5]$ mm.

Standard Deviations of the Differences (Predictions Minus Truth) and (Updates minus Truth)

	North	East	Height
Predictions	13.4	100.6	27.8
Updates	1.3	1.4	1.9

Values are in [mm]. In this analysis seismic sites have been included when forming the differences, in this analysis.